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Research at the University of Hawai'i on the Humpback Whale, *Megaptera novaeangliae*

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This project is dedicated to my parents and loving step-parents who have supported my education unwaveringly and without condition, quite often at their own self-expense.

Research at the University of Hawai'i on the Humpback Whale, *Megaptera novaeangliae*

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Abstract. During the 1991 "off-season" at the University of Hawai'i's Humpback Whale Research Project, the author began work with graduate students as a volunteer research assistant. Work at the time emphasized matching animals sighted earlier in the year to animals sighted in field seasons of previous years. This was done by comparing natural markings on the photographed flukes of each animal to an extensive catalog. Data on resighted whales were noted and recorded, and previously unseen whales were added to the database. This data was used to estimate the size of the Central and Eastern North Pacific population of humpbacks. Data from the years 1975-1989 indicate a population of 5181 individuals. However, testing showed that one or more of the assumptions during those years was violated. A wide confidence interval, therefore, accompanied this estimate. Data from 1978-1982 showed no assumption violations and a population estimate of 2364 individuals with a very narrow confidence interval. The population estimates also seemed to show an exponential pattern of growth. Work was also done with the field team in January of 1992 on the Big Island, where preparations were made for four months of daily data collection. Humpback whale song recordings and fluke photographs were collected for later analysis.

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INTRODUCTION

Humpback whales, *Megaptera novaeangliae,* average about 15 meters in length and about 36 metric tonnes each, with females being slightly larger than males. The most distinguishing feature of the humpback whale is its large pectoral fins which can grow up to 5 meters in length. These massive pectoral fins are the basis for its genus name *Megaptera*, meaning "large wing."

These whales are also very well-known for the complex and eerie "songs" that they sing only during the winter season (Payne and McVay, 1971). The song begins each year as the same song sung at the end of the previous year's season but then changes and evolves into a new song as the season progresses. Only the males sing, and they sing at volume levels of up to 150 decibels. This can be heard for distances of at least several kilometers. The meanings of these vocalizations are still not understood.

Whales are mammals in the Order Cetacea. Humpbacks are in the Sub-order Mysticeti. Mysticetes have large plates called baleen in their mouths instead of teeth. Baleen plates work like combs to strain fish and small food items called plankton out of the water. Humpback whales also differ from the odontocetes, or toothed whales, in that they have two blow-hole apertures instead of only one. This can be identified occasionally by the shape of their "blows," even at a distance.

Humpback whales are found in all the oceans of the world in both hemispheres, yet there seem to be very distinct, separate groups of them that never meet (Evans, 1987). They follow migratory routes up to 4,500 km long (Baker *et al.*, 1985)—one of the longest migratory routes known to occur in the animal kingdom. In the summer the humpbacks move to polar feeding areas rich in plankton, such as Alaska in the case of the Central and Eastern North Pacific humpbacks, and then to tropical breeding/calving areas in the winter (Donovan and Tillman, 1986). In the North Pacific, these wintering locations include Hawai'i, Mexico, Japan, and California. However, due to the opposite seasons in the northern and southern hemispheres, one group of humpbacks will always be heading to polar waters while the other is making its way toward the tropics. This isolation of humpback groups makes it possible to conduct special types of comparative scientific research not possible with other free-roaming species. For example, a simple ecological question such as stock size would become immeasurably difficult if the individuals could not be constrained in at least some way.

The University of Hawai'i Humpback Whale Research Project (UH HWRP) is an ongoing scientific endeavor of the Kewalo Basin Marine Mammal Laboratory (KBMML) that started in 1975. Since its beginning, it has been able to shed light on many questions about the life history and status of the endangered humpback whale. Under the direction of Dr. Louis M. Herman, the UH HWRP has provided much behavioural information and other data to support the publication of papers useful to the conservation and management of the species (Baker, 1985; Baker and Herman, 1981; Baker and Herman, 1984; Baker and Herman, 1987; Baker *et al.*, 1982; Baker *et al.*, 1985; Baker *et al.*, 1986; Bauer, 1986; Bauer and Herman, 1986; Herman, 1979; Herman and Antinoja, 1977; and Herman *et al.*, 1980). This work has centered mostly on studies of the whales sighted in Hawai'i and Southeast Alaska, due to their significantly higher densities in these areas, with studies being done to a lesser degree in the other North Pacific areas.

The primary means of data collection is through a benign and non-intrusive derivation of the "mark-and-recapture" technique called photographic identification: photographs are taken of the tail flukes of whales sighted in Hawai'i and Southeastern Alaska, and by keeping a catalogue of these photographs, a re-photographed whale can discriminated from one that has not been previously photographed. This is done by comparing the individual markings on the animal's photographed tail flukes to those "fluke shots" accumulated in the catalogue of "marked," or identified, individuals. These fluke markings are unique to each whale in the same way that a set of fingerprints is unique to each human, since no two flukes are alike. Therefore, a "resight" would have a matching fluke in the catalog, while an animal without a match would be the first such record of that individual and would be added to the catalog.

Recording the number of resights matched and the total number of whales sighted each year allows for the employment of certain statistical methods to estimate the size of the population being studied. In addition, the photographic identification technique can give information on whether or not humpbacks form long-lasting relationships among themselves, have truly separate breeding populations, or have different migratory routes and feeding ranges. This information can be obtained since the life histories of <u>individual</u> animals can be identified and followed over time if behavioural and geographical data are collected along with the fluke shots of each animal (Katona *et al.*, 1979). These kinds of data allow scientists to have a better understanding of the species and how human activities might affect their populations.

The Skill Project

An appointment was set up with Rick Coleman, a graduate student working at the UH HWRP, to discuss an internship with the project. My proposal was accepted, and I started work immediately, learning the details of the project "on-the-job." By getting involved in this well-known project, it was hoped that an edge to my career would be gained from the experience and that a realistic view of what it is like to work on an important scientific investigation would be acquired.

In the Fall of 1991, I identified newly-sighted and resighted humpback whales that were seen during the 1990 field study. I also helped organize and prepare the 1992 field study and temporarily accompanied the field team to assist in data collection on the Big Island during the month of January. During the Spring of 1992, I learned how to use a spectrograph to analyze recorded whale songs. My main goal for this skill project, however, was to calculate an estimate of the humpback whale population in the Central and Eastern North Pacific using a logarithmic technique and to compare this estimate with those in the current literature. This was done by collating 15 years of data collected by the UH HWRP since its inception.

The main reason for this population estimate was to learn how to answer this sort of ecological question for myself. Then I could compare my estimate to the estimates in the literature to form opinions about the different procedures used. By learning the different possible methods used for this type of study along the way, I would satisfy my own curiosity of why there are so many discrepancies between population estimates in the literature, and I would get a feel for how much methodologies and personal contributions play in drawing conclusions based on data ultimately collected from the same source, the Central and Eastern North Pacific humpbacks.

THE WORK

Preparations

There are two parts to the work done: the field work and the lab work. Each year's research for the project begins in the winter with field work in the waters off of the Kohala coast on the Big Island of Hawai'i (Fig. *1*. Note: Figures and photographs are the work of the author unless otherwise specified.). The field location was previously Maui but was moved to the Big Island around 1988 due to increasing levels of disturbing vessel traffic around Maui (Coleman, R., pers. comm.). Vehicle, staffing, and housing arrangements must all be made far in advance of the field work to insure smooth procedures. About a week before setting up "Whale Camp" on the Big Island, equipment and boats are moved from storage to a barge for shipment. The field team then flies to the Big Island during the first week of January, where the first priority is picking up vehicles and unloading luggage at a rented house.

When the boats and equipment are picked up, repair and preparatory projects are begun. Minor work must usually be done on UH HWRP's two research boats: a 17-foot Boston Whaler and a 16-foot inflatable Zodiac. The Zodiac must be properly assembled and inflated, as well as checked for leaks. Leaks are patched using a two-part glue. On the Whaler, checks for faulty or fouled wiring in the bilge, electrical systems, and marine radio must be made. Other work includes small repairs on items such as broken hatch covers, etc.

In the Field

Around 8:30 a.m. each morning, equipment is loaded into the boats. The boats are then launched from either the Puako ramp or the Kawaihae ramp. When available, a mooring is reserved

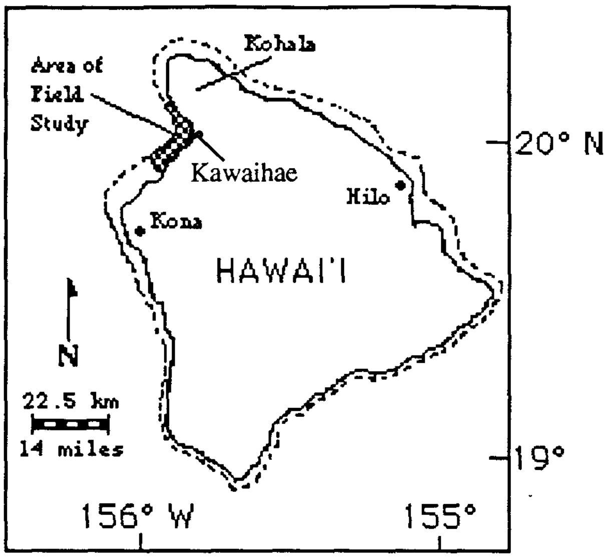


Fig. 1. UH HWRP's field study area. The dotted line surrounding the island represents the 100 fathom isobath. (Modified from Herman et al., 1980.)

for the Whaler at the Kawaihae harbour. The field team works its way up and down a 16 kilometer stretch of coast centered around the harbour. The field study area is surveyed for whale activity the entire period of time from 9 a.m. to 4:30 p.m. The boats are then taken back and unloaded, and the equipment is stored back at the rental house for safe-keeping and maintenance.

When a whale's "blow" is sighted during one of these coastal surveys, the boat maneuvers closely to the whale's position. One of the field team members works as a data recorder and records the time interval between surfacings in order to predict surfacings while the driver tries to position the boat so that the whale's flukes are as closely lined up in front of the photographer as possible while the sun is as directly behind the photographer as possible to "front light" the flukes.

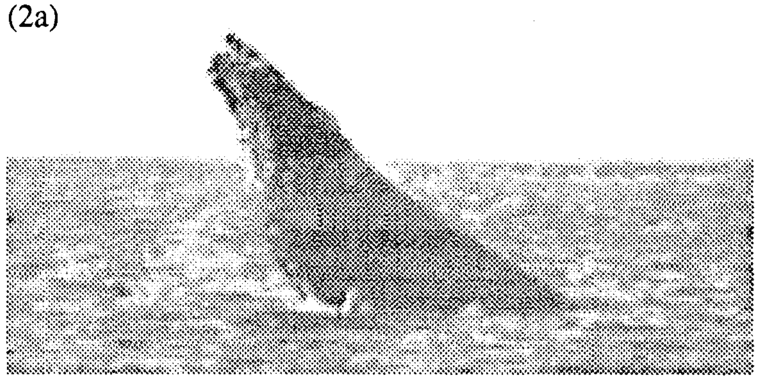
After a period of blows by a humpback at a surfacing, it characteristically humps its back and then lifts its flukes out of the water just before going down for an extended period dive called a "sounding." A good fluke shot can be anticipated by recognizing the beginning of this series of actions, called a "fluke-up," and it cues the photographer as to when the shutter should be released.

35-mm black and white film is used instead of color to bring out the contrasts in the photographs. In addition, the f-stop is reduced one stop more than required to bring out the contrasts in the markings of the flukes. The cameras are equipped with 300-mm telephoto lenses for enlarged detail of the fluke markings. Cameras are also equipped with motor drives to allow multiple shots to be taken at high speed.

To combat the effects of constant boat movement on the photographs, 400 ASA film is used and the cameras are set on the shutter speed priority program. The combination of high-speed film and shutter priority allows the photographer to set the shutter speed at 1/1000 second to stop boat motion while the camera calculates the appropriate f-stop for the shutter speed and current light conditions. Then the photographer sets the f-stop one setting below that calculated by the camera and the fluke shot is ready to be taken. These camera adjustments are made just prior to the anticipated surfacing time predicted by the data recorder.

When the whale flukes-up, usually two or three photographs are taken in rapid succession just to make sure that at least one of them was timed correctly to capture all of the detail in the flukes.

(2a)



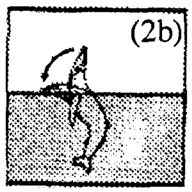


Fig. 2a, b. A head slap--an example of an aerial display. The functions of these above-water display behaviours are not yet understood. 2b shows the motion of the head. (2b from UH Sea Grant College Program, 1985.)

Important data corresponding to the fluke shot are then recorded by the data recorder onto the shipboard "podmaster data form." The data include the fluke shot's film roll number and film exposure number as well as the assigned pod number, the area of observation, and the type or behavioural role of the humpback observed in the fluke shot. The behavioural role can take on any one of the following classifications on the data form: escort, mother, calf, cow, or singer. Other common behavioural observations recorded in the log books were aerial displays such as pectoral fin slaps, tail slaps, and head slaps (*Fig. 2*).

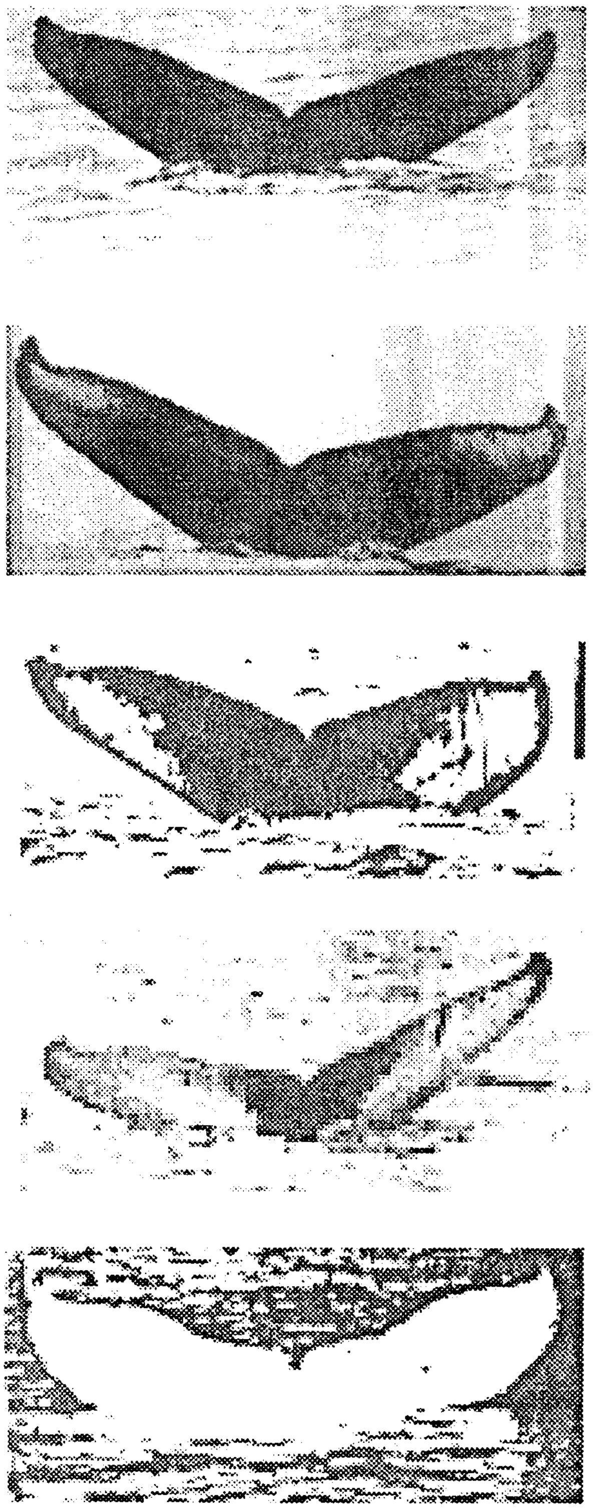
This data is later entered on the computer at the house and printed onto labels. Contact sheets are then made from the negatives and the best fluke shots are selected and made into prints. The labels are next affixed to these prints which are finally ready to be sorted and arranged by the amount of white pigmentation on each fluke.

There are five percent-white pigmentation classes assigned: 0, 25, 50, 75, and 100 (*Fig. 3a-e*). By dividing the fluke shots into these different pigmentation classes, a great deal of time and effort is saved by not trying to match a fluke against every existing photographic record in the catalogue but rather only to the number of photographic records in the catalogue that are in the fluke shot's same pigmentation class.

After all these procedures are completed, "fluke matching" begins at the house for within-season resights. Fluke shots of the same individual seen on different occasions are grouped together so that the total number of individual whales sighted can be tabulated at the end of the field season. This within-season fluke matching follows the same techniques outlined by Katona *et al.* (1979) for across-season fluke matching.

Recordings are also made of the humpback whale's characteristic song. Single animals that are spotted usually denote roaming males who are likely to be singing. When these probable singers are sighted, hydrophones are dropped over the side of the boat to a depth of 10 to 20 meters. The hydrophones are connected to a pre-amplifier to provide the necessary signal for the portable Marantz cassette tape recorder (*Fig. 4*) and to monitor the water for underwater vocalizations by the humpbacks.

Fig. 3a-e. *The five percent-white pigmentation classes. (3a-e by UH HWRP.)*



(a) 0%

(b) 25%

(c) 50%

(d) 75%

(e) 100%

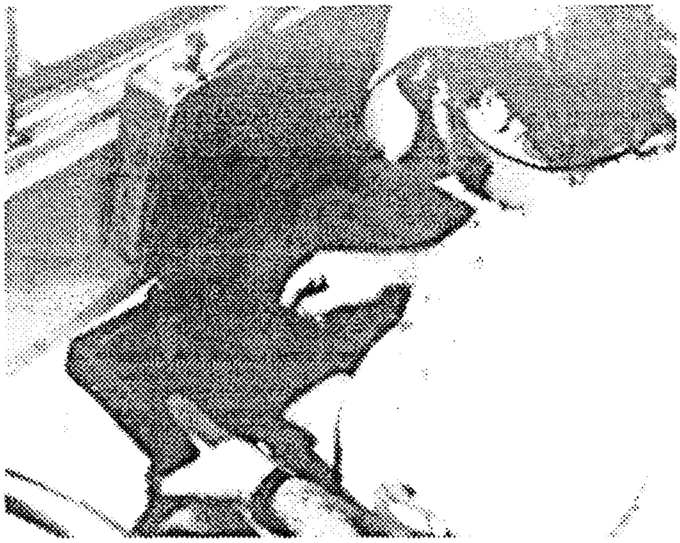


Fig. 4. The portable Marantz cassette tape recorder used to record whale songs. Hydrophones are hooked up to a pre-amplifier and then hooked up to the Marantz. Here, Adam Frankel demonstrates how to correctly adjust the recording level and attenuation settings on the Marantz.

The recording level can be adjusted on the Marantz to compensate for weak signals. However, if the hydrophone is not deep enough or there is high wave action, a high recording level will tend to increase the amount of background noise picked up by the tape. This noise is usually caused by water slapping against the boat's hull or snapping shrimp. On the other hand, if an animal is vocalizing fairly close to the boat, the large amplitude of the whale song may saturate the hydrophone. Therefore, an attenuator switch on the Marantz can be used to cut 10, 15, 25, or 50 decibels from the signal strength in order to reduce harmonic distortion and to allow manageable recording level adjustments. These are the preferred recording situations unless the whale song's amplitude is still saturating the hydrophone even at the highest attenuation setting; by cutting some of the strength from the incoming signal, background noise can be almost entirely cut out of the recording.

In the Lab

When the field work is finished in April, the main data analyses can begin. Work begins in the summer and during the fall on across-season fluke-matching in the manner documented in Katona *et al.* (1979).

Resighted animals are assigned resight numbers, and these are printed on all of the fluke shots of the corresponding individuals. The resight numbers are next appended to the rest of the corresponding fluke shots' information stored on computer. Then the best fluke shot of each individual is chosen, and this photo goes back into the main catalogue to represent the individual while the extras are put into a supplementary catalogue of resights.

A total of approximately 20 resights from the zero and 25 percent-white pigmentation classes were identified and logged for 1990 by the author during the period of September through December.

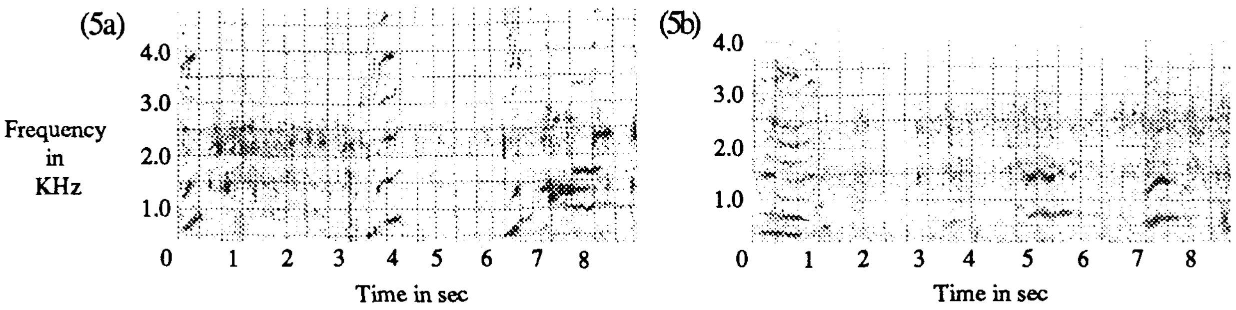


Fig. 5a, b. Two spectrographs of sampled humpback whale song recorded on 11 January 1992. Each is a different part of a song sung by the same animal that day. The darker the marks on the graph, the higher the amplitude, or volume, of the sounds. The humpback vocalizations are the dark streaks that occur at t=0, 3.5, and 6.5 sec in 4a and at t=0, 5, and 7 sec in 4b.

The discovery of these 20 resights represents the culmination of over 20,000 visual comparisons (ca. 125 new fluke shots x ca. 700 catalogued 25% and 0% fluke shots ÷ 4 workers). 1990's fluke shots brought the number of whales photographed in the UH HWRP's catalogue up to over 2600 individuals.

Spectrographic analysis of the whale song recordings is also done after the field season using a Kay Elemetrics Model 5500 Signal Analysis Workstation Machine. This spectrographic analysis produces a frequency vs. time graph of the recorded whale song. This quantifies the auditory data so that similarities or differences between songs can be analyzed such as in Helweg *et al.* (1989), Guinee *et al.* (1983), and McSweeney *et al.* (1989). Theoretically, the percent discrepancies can be calculated from this data and the significance of variance estimated. This information along with corresponding photographic identification data can be used to determine if animals pass the theme of the song on from one individual to another and, if so, how much mixing occurs between animals of different geographical locations.

Since the main features of interest in a whale's song are the changes in its frequency, a narrow-band sampling setting (ca. 29 Hz) is chosen to sharpen the resolution of the frequency plots (Beecher, 1988). Since most of the vocalizations that are sampled all occur at low frequencies, the range is set on the Kay 5500 at zero to four KHz. Also, since recording quality can not always be consistently reproduced, an analysis attenuator can be set on the Kay 5500 to cut out extraneous background noise from the spectrographic analysis. This setting is analogous to the attenuator function on the Marantz.

Two ten-second samples from a recording made of a single whale on 11 January 1992 were used for training on the Kay 5500. These samples (*Fig. 5a,b*) represent recurrent phrases in two different themes of the song recorded that day. Both samples are of phrases consisting of three vocal units. They are both quite different in their timing, their frequencies, and richness, or number of harmonics. An example of these harmonics can be seen as the five repetitious markings above 1.0 KHz in *Fig. 5a* at t=4 seconds. The dark bands in the background centered around 2.5 and 1.5 KHz in the two spectrographs denote water slapping against the boat's hull. Other extraneous noise included the sound of the hydrophone cord rubbing against the side of the boat. This appeared as a very dark band at around 25 Hz but was cropped out of the figures to avoid distraction.

THE POPULATION ESTIMATE METHOD

The method used for the population estimate was derived from approximately four months of mathematical work (Appendix I) done by the author. However, a subsequent search through the literature for information on confidence interval calculations revealed that this type of method had already been described (Tanaka, 1951). The method described in Tanaka (1951) gives the same results, but for simplicity's sake, keeps the plotted data in Quadrant I of the graph by using the inverse of the resight/sample size ratio derived by the author. This reverses the slope of the least squares line and causes a reflection about the y-axis since the log of an inversed fraction is larger than one and, therefore, positive instead of negative.

The basic premise is to use logarithmic scales that enable the use of linear regression mathematics to calculate population size. The equation is in the form

$$y = a + bx \tag{1}$$

where the y-axis is the cumulative number of individuals sighted ("marked"), the x-axis is the log [sample size ÷ number of resights], [a] is the y-intercept of the line, and [b] is the slope. In the "line of least squares" model used for this paper,

$$b = \frac{\Sigma (X_i - \overline{X})(Y_i - \overline{Y})}{\Sigma (X_i - \overline{X})^2} \tag{2}$$

and

$$a = \overline{Y} - b\overline{X} \tag{3}$$

where

X_i = log [sample size ÷ resights] for year (i)

and

Y_i = cumulative number of individuals sighted ("marked") at the beginning of year (i).

The population estimate, using this method, is defined as the antilog of a theoretical value where x=0. This theoretical value is [a] from Equation 3--the point on the graph where the calculated least squares line intercepts the y-axis.

A more detailed account of linear regression techniques can be found in Sokal and Rohlf (1981); basic tutorials can be found in Krebs (1989).

95% confidence limits were calculated using information from Sokal and Rohlf (1981) and Krebs (1989). A test of the model's assumptions, described in the latter text, was also performed. The assumptions were:

1) population size remains constant, or "closed," without recruitment or losses over all years sampled;
2) all animals have equal chances of being sighted;
3) sampling is random.

One of the advantages of the Tanaka model is that a relatively good estimate of population size is still possible even when some of its assumptions have been violated (Krebs, 1989). This is because errors in the data will be "averaged out" with the rest of the accumulated data and will be minimized unless the errors, themselves, begin to form a strong trend in the data over the years of the study.

A "cohort" population growth table was also created and compared against the Tanaka estimates and confidence intervals. This table was created by estimating the number of calves that should be born each year and adding these numbers to a base population estimate. The cohort table was based on a Tanaka estimate of 2680 animals for 1981, and it assumed that 25 percent of the population's animals were mature females with a calving rate of 0.37 (Perry *et al.*, 1988). The calving rate predicts that 37 percent of the mature females gave birth to calves that survived their first migration to Alaska. Mortality was not taken into account in this table.

UH HWRP's main database is on the university's mainframe computer. The necessary parameters for the Tanaka model were extracted from this database using a program in the SAS language. Rick Coleman wrote this program at my request since learning the SAS language to the degree of proficiency necessary was out of the scope of this project's time frame.

RESULTS

The raw data have been withheld at the request of the UH HWRP.

Data from the years 1975-1989 indicate a y-intercept of 3.7144 which corresponds to a

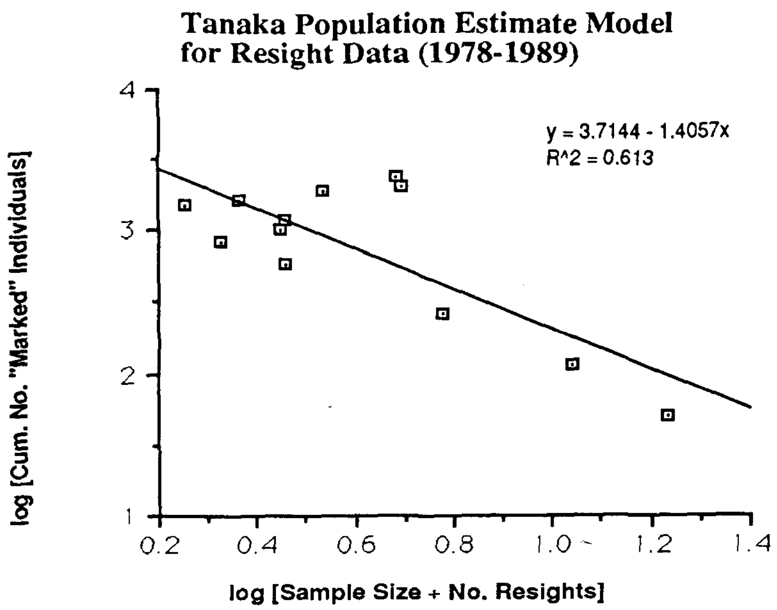


Fig. 6. *Tanaka model for resight data (1978-1989). The data should follow a linear regression to the y-intercept (3.7144).*

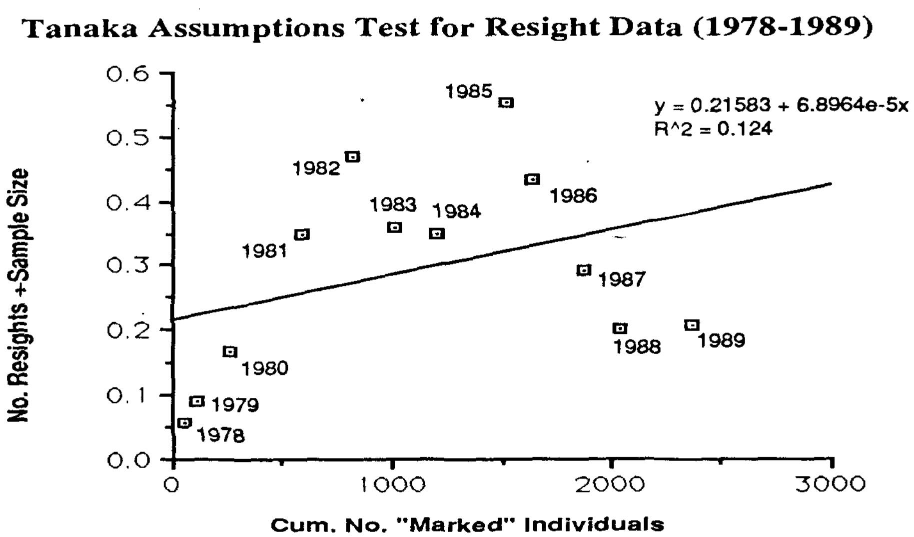


Fig. 7. *Test for assumption violations (1978-1989). The data should conform to a straight line with a positive slope if the assumptions of the model are met.*

Tanaka Assumptions Test for Resight Data (1978-1982)

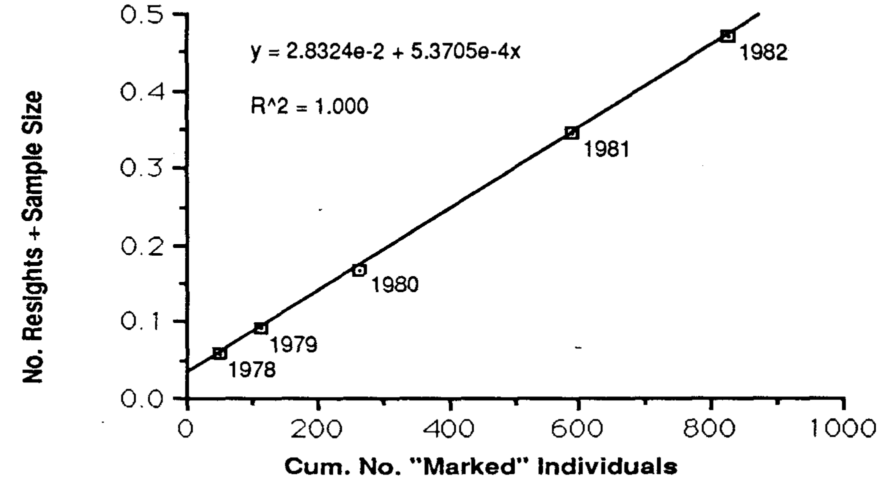


Fig. 8. *Test for assumption violations (1978-1982). The data should conform to a straight line with a positive slope if the assumptions of the model are met.*

Tanaka Population Estimate Model for Resight Data (1978-1982)

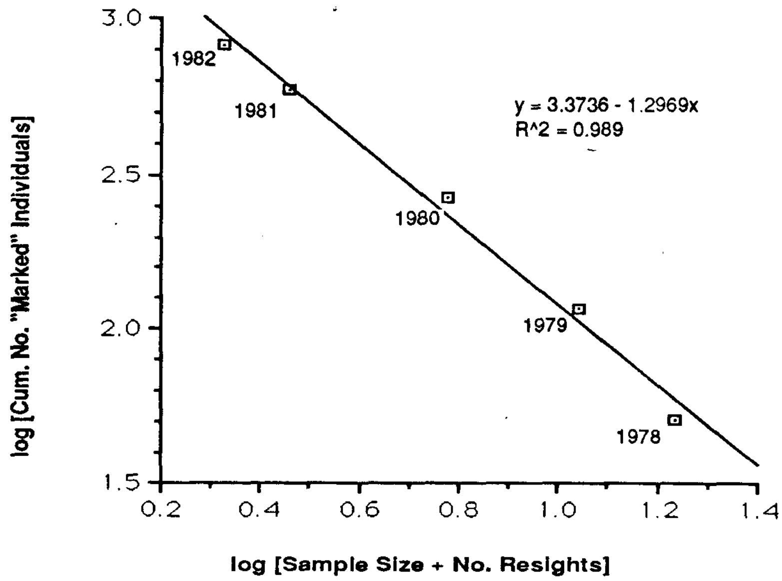


Fig. 9. *Tanaka model for resight data (1978-1982). The data should follow a linear regression to the y-intercept (3.3736).*

Table 1. Estimates of Central and Eastern North Pacific humpback whale population size over time with associated statistics.

Based on Years	y-intercept	Tanaka Estimate (antilog of y-int.)	95% Confidence Lower Limit	95% Confidence Upper Limit	Cohort Table Estimate
1978 - 1982	3.3736	2364	2192	2549	2928
1978 - 1983	3.4701	2952	2664	3271	3199
1978 - 1984	3.5545	3585	3208	4008	3495
1978 - 1985	3.5562	3599	3314	3910	3818
1978 - 1986	3.6052	4029	3723	4359	4171
1978 - 1987	3.6689	4666	4158	5235	4557
1978 - 1988	3.6912	4911	4292	5618	4978
1978 - 1989	3.7144	5181	4418	6075	5439

population estimate of 5181 individuals (*Fig. 6*). The correlation of the data to the predictive line is fairly high ($R^2 = 0.613$). Note: the first couple of years do not appear in the model since there were no resights, however individual animal sightings were still being accumulated during those years.

The data from 1975-1989 should meet all the assumptions of the model if they fall along a straight line with a positive slope using the test described in Krebs (1989). The poor correlation coefficient ($R^2 = 0.124$) indicates that a good deal of the data violate one or more of the basic assumptions (*Fig. 7*). However, a closer look at the graph reveals that the years 1978-1982 appear to yield a straight line with a positive slope.

The R2 value when considering only the years 1978-1982 ($R^2 = 1.000$) leaves little doubt that the assumptions were being met during those years (*Fig. 8*). The Tanaka model for just the data from 1978-1982 reveals a very high correlation coefficient ($R^2 = 0.989$), implying a great confidence for an estimate using these years as a basis. The data from 1978-1982 produce a y-intercept of 3.3736 corresponding to a population estimate of 2364 animals (*Fig. 9*).

The binomial confidence intervals for the first 10 population estimates, summarized in Table 1, were based on n-2 (the number of years of data used for each estimate minus two) degrees of freedom ($\partial.f.$) in the manner of Sokal and Rohlf (1981). While the last two confidence intervals were estimated using $n=\infty$ $\partial.f.$ because of the large number of samples ($s > 10$) used to make the estimates (Krebs, 1989).

Except for 1982, cohort predictions are amazingly comparable to the Tanaka estimates and well-within the calculated Tanaka confidence limits (*Table 1*). An exponential growth curve was calculated from the Tanaka estimates and plotted along with the data. The Tanaka population estimates seem to show a definite exponential pattern (*Fig. 10*). The cohort population predictions also show a high adherence to the same exponential curve.

Tanaka and Cohort Population Estimates for 1981-1989

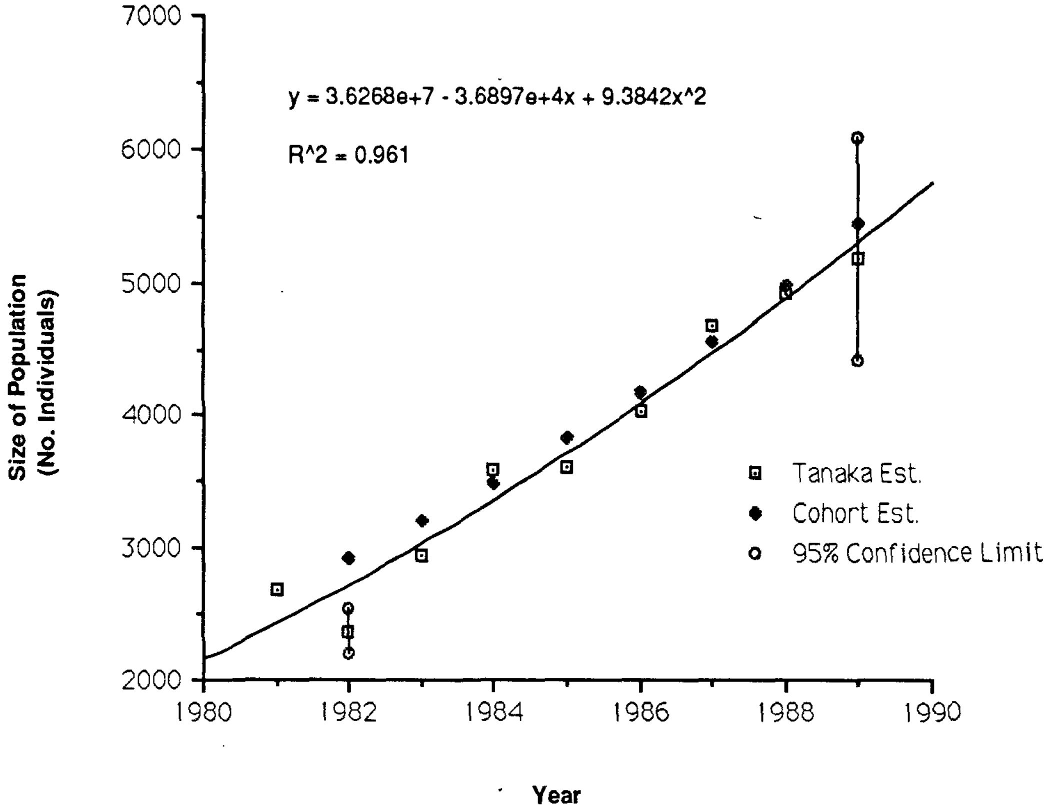


Fig. 10. Comparison of Tanaka population estimates and cohort predictions. The data conforms to an exponential growth curve.

DISCUSSION AND CONCLUSIONS

It is apparent from the data that not all of the assumptions of the model were met between the years 1983-1989. However, the problem probably does not lie in any one area. The "equal catchability" and/or "random sampling" assumptions of the model may not have been satisfied; the samples appear to be random in field methodology, but they may not actually be individually independent replicates due to the same study areas being sampled over and over again for the majority of the observations. The assumption that appears to have been the most severely violated is the assumption that the population size remained constant during these years.

The population appears to be on the rise—from estimates of about 1000 in the late 1960s and early 1970s to about 2000 in the mid-1980s (a review of some of these estimates can be found in Baker and Herman, 1987). North Pacific humpbacks came under protection of the International Whaling Commission (IWC) in 1966 (Kaufman and Forestell, 1986). Given an estimate of seven years for newly-protected females to mature and produce their first young, it is plausible that it would have taken approximately 25 years for a noticeable change in their population to be observed. This increase in the population would most definitely be a violation of the "static population" assumption. The Tanaka model, unlike other methods, however, can still give good approximations of the population size (Krebs, 1989). The only trade-off with such violations is an increase in the size of the confidence intervals calculated for the estimates.

In any case, this study implies that the Central and Eastern North Pacific population of humpback whales is substantially larger than previously estimated. New research just being done seems to also support the idea of a population larger than previously thought. The Pacific Whale Foundation's (PWF) Paul Forestell, in a recent newspaper article (Tanji, 1992), estimated the number of humpbacks that visit Hawai'i during the winters to now be around 2500. According to Forestell (Kaufman and Forestell, 1986), the percentage of whales that visit Hawaiian waters is around 60 percent. This would imply a Central and Eastern North Pacific population of around 4167 ($100 \div 60 * 2500$). This is just slightly lower than the 95% confidence limit for the 1992 Tanaka estimate.

The PWF collects its data off the coast of Maui using similar photographic identification methods and, occasionally, from the waters around many of the other islands when using aerial surveying techniques. Data released by the PWF and printed in the Tanji article also show an exponential trend in the number of whales seen over two-year periods from 1978-1992. This observation also coincides with the conclusions drawn here. The cohort predictions graphed in Figure 10 are extremely close to the estimated exponential growth curve calculated from the Tanaka estimations. If the Tanaka estimations are valid, they provide more supportive evidence for the Alaskan-based calving rate estimate of 0.37 calves per mature female per year and the 25 percent mature female population component (Perry *et al.,* 1988). Although from looking closely at the graphed cohort data, it appears that it is just a slightly sharper curve than the Tanaka-estimated growth curve.

Little is known about the Central and Eastern North Pacific population's operational sex ratio, or the number of sexually mature males to sexually mature, <u>receptive</u> females. This could be the source of the cohort deviation from the growth curve. Mortality could be another. More studies should be focused on these two factors so that better predictions of population size for any given year can be made. When these predictions are compared against highly accurate population estimates, determining when problems are occuring and when management programs are being successful will become easier. For now, though, it appears that non-interference has been and will probably continue to be the best thing we could ever do for their recovery considering the logistical problems of trying to "manage" such a free-roaming, huge animal as the humpback. It appears that they are well on their way down the road to recovery.

EVALUATION OF LEARNING

I was approximately six months out of phase with the research schedule, beginning my work in the lab at the end of the year instead of in the field at the beginning of the year. However, for the sake of continuity, I documented the year's research procedures in their correct order, most of which I had direct involvement in. I helped move boats and equipment to the barge for shipment to the Big Island. I learned how to solder faulty wiring in marine radios, hydrophones, and pre-amplifiers. I learned how to properly assemble and inflate a Zodiac as well as how to check it for leaks. I also learned how to patch these leaks properly using two-part glue. On the Whaler, I learned how to check for faulty wiring in the bilge, and helped install a new antenna. I also repaired and re-varnished a broken hatch cover for the Whaler.

Adam Frankel instructed me in the use of the Canon cameras with the variable-speed motor drives. He also taught me how to set up the recording equipment for taping whale songs. I refined these equipment skills and learned the basics of launching, docking, and mooring small motor boats during the course of our daily whale observation activities. I also recorded data for the group while out in the field. However, I did not get a chance to do within-season fluke-matching due to the fact that I was with the field team for too brief a period.

I felt that I really learned a lot from the experience. It was thrilling to get the chance to work on almost every aspect of the research being performed by the UH HWRP. By working on this project I was able to be a part of the entire scientific process—theory, field work, lab work, and conclusions. Learning how to use scientific instrumentation, such as the Kay 5500 and the hydrophone, and interpret their output will no doubt prove useful to me later in future studies. In conclusion, I would like to note that I feel confident that I have gained skills and knowledge through this project that will be a great advantage to me as I pursue my academic and career goals.

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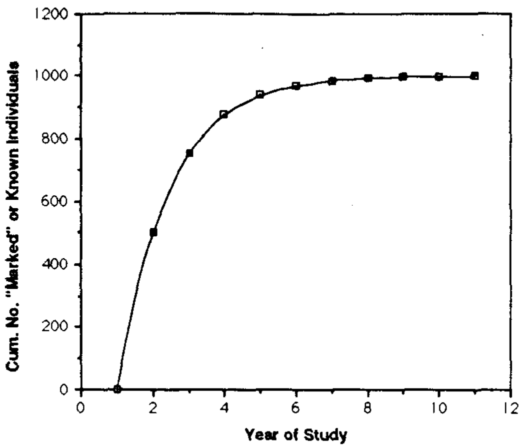
(11a)



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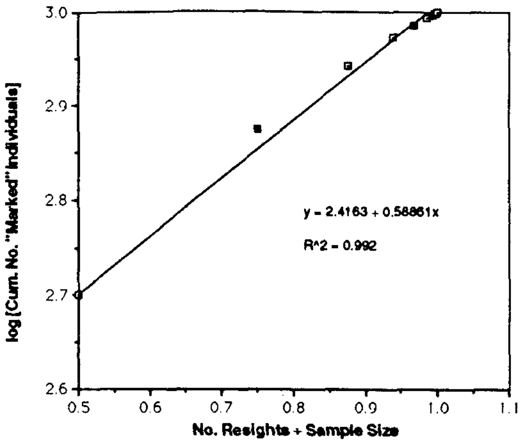
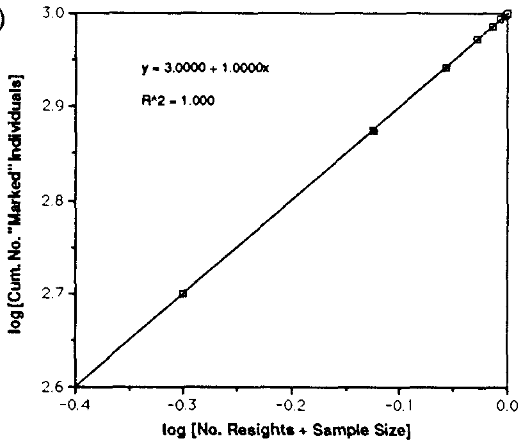


(11c)



Figs. 11a-c. The data transformations leading to the population estimate model. All three graphs are based on a hypothetical study of a population of 1,000 individuals with 500 individuals being sighted per year. Since the changes in the data plotted in 11a have an exponential basis, using log scales eventually supplies a model of linear regression to the y-axis (11c) that can be used to estimate the population. Note that the antilog of the y-intercept in 11c, 3.0, is equal to 1,000. See text.

APPENDIX I: A Description of the Population Estimate Model

The analysis of photographic identification data can be used to estimate population size. Logically, as time goes on, resights should become more frequent and previously unsighted whales should become harder to find.

If the number of individual animals that have been "marked" each year by a model study were to be plotted over a long period of time on a graph using time as the x-axis and the cumulative number of "marked" individuals sighted as the y-axis, the resultant curve would resemble an exponential function approaching an upper limit representing the actual population size (*Fig. 11a*). Of course this would still only be an estimate due to the fact that animals are dying and being born at different rates for the duration of the study, and this would affect the population estimate since these variable rates cannot be accounted for precisely in the mathematics.

A catch-22 comes into play using this particular method, however, since it is impossible to determine the upper limit of this curve accurately without already knowing the population statistics well-enough to know the function of the curve. Also, variable rates of "sampling," or animals sighted per season, and sampling error would change the curve yearly, making the use of the function as an accurate determination of the curve's upper limit nearly impossible.

One of the ways around this, however, is to simplify the above-mentioned exponential function into a more easily predictable linear function. This can be done by decreasing the vertical distortion on the graph through the use of a log scale in the y-axis. Also, the problem of yearly sample size variation should be addressed by converting the time axis into a resights/sample size ratio axis which will work as a function of time since the number of resights seen per season should increase each year. This change will allow for the placement of data points in a proportional time index relative to the sample size for each year's data (*Fig. 11b*). In other words, the data points for each year will still fall in a chronological order along a straight line if no great resight sampling errors occurred, but they will not be plotted uniformly across this line. They will be spaced across this line in proportion to the resights/sample size ratio increasing each year.

This manipulation yields a predictable linear curve that has a predictable one unit x-axis range since the time axis has been changed into a ratio axis where it is impossible for the plotted data to have more resights in the sample than the number of individuals sighted in the sample itself. This results in a maximum resights/sample size ratio of 1:1. Therefore, the y-axis upper limit of the curve, or population estimate, will occur exactly at the point where the x-axis ratio equals 1:1 on the linear curve.

To make the determination of the population estimate easier when using real data instead of a model, this endpoint can be made to occur at the y-intercept by changing the x-axis to a log scale, as well (*Fig. 11c*). Since the log of a 1:1 ratio is zero, this causes the location of the population estimate point to occur at x=0, or the y-intercept. The x-axis log scale also decreases horizontal distortion of the data points that is not readily ascertainable by simple examination of the graph. However, this distortion becomes quite apparent when the correlation coefficients of the log-log and semi-log graphs are compared (1.000 and 0.992 respectively).

When real data are plotted on this log-log graph each year as data are accumulated, a "line of least squares" should be calculated from the data that passes through all of the plotted data points and the y-axis. Then the population estimate is calculated by taking the antilog of the line's y-intercept value to compensate for the graph's change in scale. In addition, the linear equation of the least squares line will act as a useful way to describe, compare, and represent these population estimate models.

To aid in the understanding of the overall transformation of the data, some of the photographic identification data for the hypothetical population of 1000 individuals plotted in Figures 11a-11c are given in Table 2. Looking at year one, no whales have previously been seen (*Fig. 11a*) . 500 individuals are sighted in year one, and there are no resights since no whales had previously been seen. Data can not be used in the Tanaka model until there is at least one resight and one "marked" individual from a previous year since the log of zero is undefined. The next year there is a total of 500 individuals "marked" from the first year. This means that half of the population is "marked" or known at the beginning of year 2 ($500 \div 1000 = 0.5$). During year two, 500 individuals are once again sighted. Half of these individuals should theoretically already be known from the previous year. The ratio of these resights to individuals sighted (0.50) during the year is then transformed by taking its log (-0.301), and then it is plotted on the x-axis against the log of the accumulated 500 previously "marked" individuals (2.699) (*Fig. 11c*). The 250 individuals from year two that were not resights are then added to the cumulative number of "marked" individuals known for year three. This now means that 75 percent of the population is "marked" ($750 \div 1000 = 0.75$). Therefore, of the 500 individuals sighted during year three, 75 percent (375) should theoretically be resights. Then the data are again transformed and plotted (x=-0.125, y=2.875; *Fig. 11c*). When enough data is plotted in this way, the least squares line can then be fitted to the data, the y-intercept calculated, and the population estimate determined.

Table 2. Some of the hypothetical mark-recapture data for Fig. 11a-c. Based upon a population of 1000 individuals. M = cum. no. individuals sighted ('marked") at beginning of year; SS = no. individuals sighted during year; R = no. individuals sighted during year that have also been sighted in a previous year.

Year	M	SS	R	R/SS	log [R/SS]	log[M]
1	0	500	0	0	*	*
2	500	500	250	0.50	-0.301	2.699
3	750	500	375	0.75	-0.125	2.875